MEASUREMENTS OF TRANSIENT AEROGASDYNAMIC FORCES AND MOMENTS

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1. Introduction

High-energy pulse aerogasdynamic facilities (piston gasdynamic units, shock tubes, vacuum chambers) are an effective means of researches of modern flight vehicle characteristics for simulation of flight conditions with large speeds at large/small altitude. Short duration of the running cycle of these facilities (0,001-0,1ñ) creates certain difficulties for measurement of aerogasdynamic forces and moments.

The realization of such measurements can be provided, taking into account dynamic (mass-inertial and rigid) properties of all measuring system elements including not only instrumentation but also examined flight vehicle models and support devices [1-3]. The methodical approaches may differ depending on facilities specifications, modes and purposes of tests.

So, results of measurement by four-component strain-gage balance are corrected using measurements of acceleration (inertial forces) model and balance together with weighed object (nozzle), that provides obtaining data on nozzle loading in a frequency spectrum 0-1000 Hz at natural frequency of "nozzle-balance" system about 1500 Hz [1]. Measurement of drag force at run duration ~0,001 s is based on the concept of registration of strain waves in the measuring device, integrated with the model, freely suspended on flexible strings in a working section of a shock tube [2]. In both cases the dynamic calibration of measuring system is made. A technique of measuring loads by six-component balance without inertial forces compensation [3] is based on careful selection (with use of finite-element method) mass-inertia and rigid properties of model and balance, ensuring realization of tests at duration ~0,004 s.

The examples of realization in TSNIIMASH of measurements short duration aerogasdynamic forces and moments in piston gasdynamic units U-11 and U-7, shock tube U-12 and vacuum chambers U-22 and U-22M [4] are given in the present paper. The characteristic run duration in these facilities is 0,01-0,2 s, and loading measurements (as well as in [3]) are carried out without consideration of inertial forces.

Some methodical approaches of measuring transient aerodynamic forces and moments acted on models, hinged on aerodynamic strain-gage balances and capable to accomplish free angular oscillation (in pitch or yaw) with the large frequency in a working flow of wind tunnel, are presented too.

2. Measurement of aerodynamic forces and moments in piston gasdynamic units

Piston gasdynamic units (PGU) U-11 and U-7 are one of effective tools of aerogasdynamic researches in a range of numbers M = 6…15 and $Re_{1m} = 10^5 \ldots 10^8$ [4, 5]. Run duration is 0.05-0.2 s, and a range of aerodynamic load to be measured for the same model may be from units (large numbers M and small Re) up to hundreds (small numbers M and large Re) kilograms. The estimation showed, that the satisfactory quality of measurements (dynamic error less than 5 %) can be supplied at natural frequency of elastic – inertial system "model – balance – suspension" not less 50-60 Hz, i.e. more, than at 5-6 cycles of oscillations during measuring time period.

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Abstract

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In order to provide this condition the model should have small enough weight and moment of inertia with respect to the center of elastic system rigidity. In practice, at the model size – diameter ~160 mm and length ~400 mm, characteristic for tests in PGU, it is possible to fabricate metal model with weight ~600-800 g, providing its sufficient rigidity and strength for probable high values of dynamic pressure up to 4-5 kg /sm^2.

Besides, the same condition is provided using balance with the sufficient rigidity, that, in case of measurement of small aerodynamic loading (at small numbers Re), may be in the contradiction with required balance sensitivity. In similar cases providing necessary balance rigidity, required balance sensitivity and measurement accuracy are achieved by application of semi-conductor strain-gages instead of usual metallic foil ones (as it is made in [1]), which normal level of output signal is obtained at deformations in 10-30 times smaller, than for usual. Another way - special static calibration of the rigid strain-gage balance (with use of high-sensitivity amplifiers of output signal) in essential lower working range, than their nominal, with the subsequent calibration on standard model. The opportunity to keep high accuracy of measurements using the balance in a range of loads, essential smaller nominal, is confirmed by the data [6].

And, at last, rather important factor of sufficient high-response measuring system is the proper choice of means of fastening balance to the case of facility, its mass and rigidity should be great enough. Fastening means, as a rule, includes base sting and well streamline pylon, connecting sting with walls of the facility working section. At insufficient cross rigidity of the sting application of strained wires or crossbars in console part of the sting near the model base is very effective [7], this provides the second support of the console and permits to increase noticeably the natural frequency of the elastic system.

Considered measures were realized at balance tests in PGU. Typical time history of force and moment loading for conic model (length ~ 400 mm and mass ~ 800g) in PGU U-7 (at M~15, $Re_{1m} \sim 6 \cdot 10^6$) is illustrated in Fig. 1. In this case rigid six-component strain-gage balance was used (with the help of measuring amplifier type KWS-3073, HBM Germany, with amplification up to ~20000); measurement were conducted in a range 5-100 kg with error less than 5 %, thus the balance characteristics were corrected by results of standard conic model tests.

3. Measurement of model force loading in U-12 shock tube

One of the largest shock tubes U-12 [4] may be used to carry out aerodynamic balance tests of flight vehicle models for Mach number up to 10 and $Re_{1m} = 10^6 \ldots 2 \cdot 10^7$. The facility has run duration — 0,01-0,1s.

Similar to the above mentioned case, for realization of measurements with acceptable accuracy the natural frequency of measuring system should be not less than 50 Hz. Taking into account that here a level of dynamic pressure is much lower, than in PGU, examined models can be fabricated from less strong and light materials (for example, from reinforced foam plastic). In practice it is possible to fabricate large models (length ~ 400mm) with mass about 0,5 kg.

Tests were carried out using multicomponent aerodynamic balance of three types: piezoelectric (on basis of three-component piezodynamometer such as 9251À type “Kistler”, Switzerland), strain-gage and combined (forces are measured by piezodynamometer, and moments – by strain gauged beam). More rigid — piezoelectric balance is applied at more short-term tests.

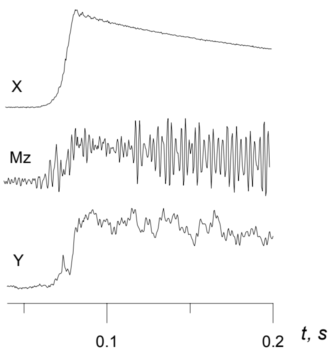

Fig. 1.

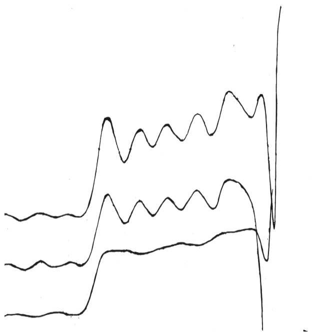

Fig. 2a.

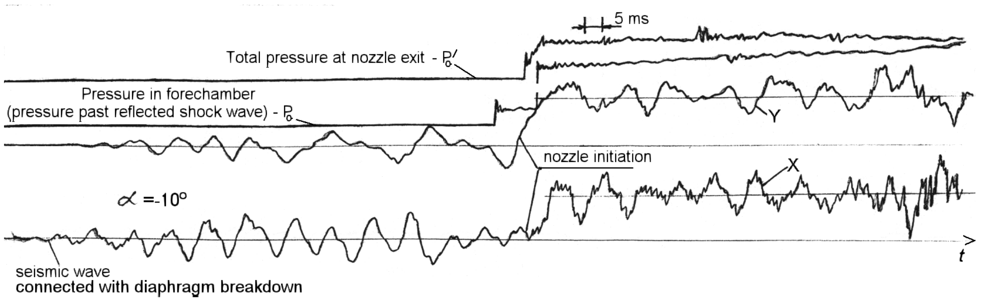

Fig. 2b.

The typical records of measured electrical signal, during balance tests in U-12 shock tube are shown in Fig. 2. The case "a" demonstrates a kind of signals measured by strain-gage balance and case "b" – by piezoelectric balance.

4. Measurement of forces and moments in vacuum chambers

Balance tests from Sections 2 and 3 are traditional, i.e. the weighed model is exposed to force influence of oncoming flow simulating flight conditions. Usually in aerogasdynamic vacuum chambers U-22, U-22M [4,8] tests are carried out for investigation of force action of engine jets (as a rule with rather low thrust) on the examined model; for example aerogasdynamic problems related to high-altitude docking-undocking are studied. Such is the study of gasdynamic loading of solar batteries panels by engine jets during docking/undocking of space vehicles at realization of the programs «Apollo-Soyuz», «Shuttle-Mir» etc. Characteristics of the tasks is a rather low level of measuring loads (tens grams - kilograms) at run duration limited by vacuum chamber filling conditions.

For vacuum chambers U-22, U-22M characteristic time of tests is 0,05-0,1 c. At allowable error of force loads definition 5-10 %, the natural frequency of the measuring system should be not less than 40-50 Hz.

At balance rigidity, limited by small measuring level of loads, the necessary response of the measuring system can be supplied with application of especially light models. Taking into account, that in considered examined tasks intensity of force influence (the level of dynamic pressure) is small enough, it is possible to fabricate model shell with very thin (~0,1 mm) walls, for example, from a special polymeric paper impregnated with pitches and heat-treated. The required rigidity of the model structure is provided by reinforced shell. Thus it is possible to

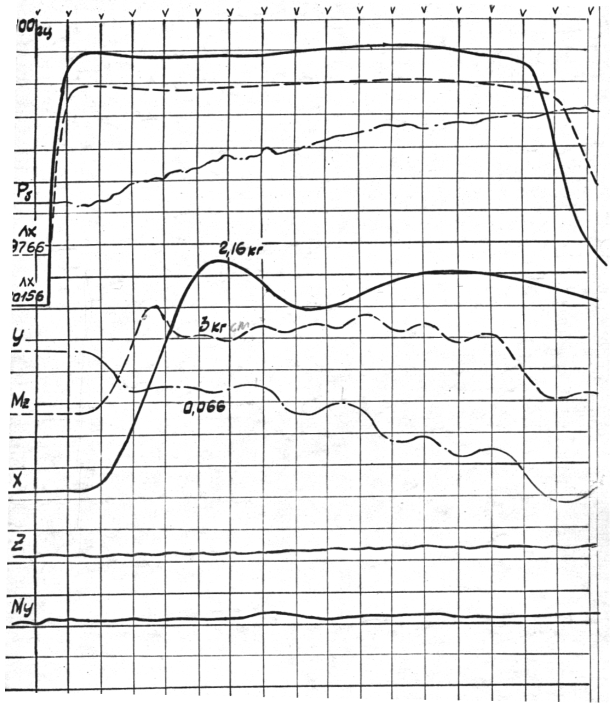

Fig. 3.

create models of weight from 10 up to 100g at reference diameter from 40 up to 100 mm and length up to 250 mm. Let's notice, that the similar shells can well work in cryogenic conditions and withstand to pulse influence of hot engine jets.

Typical character of record of balance test in U- 22M vacuum chamber is illustrated in Fig. 3.

5. Measuremenht of aerodynamic forces and moment at a model free angular oscillations

For examined model hinged on the aerodynamic balance sting, the model may execute free angular movements. Thus beside usual simulation of M and Re numbers it is possible to ensure similarity on of Newton number $Ne_2 = \rho L^5 / I_z$ (ρ – density of oncoming flow; L, Iz – reference size and moment of inertia with respect to the axis of oscillations), and the hinge axis coincides with the centre of mass of the examined vehicle. Then Strouhal number of the flight vehicle will be also reproduced at the tests. This circumstance is rather important, when the angular movements of the device are accompanied by transformation of flow structure around the model and this transformation (in zones of transition and separation) can have hysteresis character. As characteristic model scale for typical wind tunnels is 1:10 … 1:50, the free oscillation frequencies of the tested models will be in a range ~ 10 … 100 Hz. As to amplitudes of oscillations, depending on model configuration, the range of angular movements with respect to trim angle of attack may be up to ± 30° and more for cones and segments with a large vertex angle.

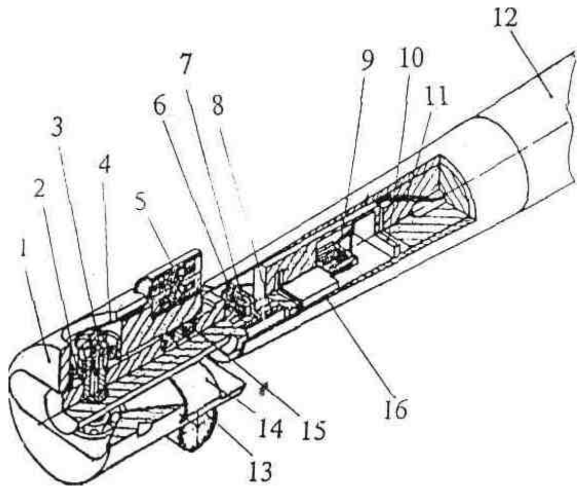

Fig. 4. Strain-gage balance combined with free oscillation device.
1 – adapter for testing model mounting; 2 – ball bearing; 3 – rod (axis of oscillation); 4, U – wires; *5,* 13 –inductive type transducers of angle rate and acceleration, respectively; 6 – sensitive element of Y-force dynamometer; *7,9* – strain gages,8, 10 – flexible elements of Y, X – force dynamometers; 12 – sting; 14, 15 – armature and inductive type sensitive element of angle attitude transducer; 16 – shield.

One of typical designs of strain-gage balance for free oscillation tests is shown in Fig. 4 [8]. During tests with such devices at model angular oscillation the registration of instantaneous values of drag X and lift Y forces, angle of attack α and angular acceleration $\ddot{\alpha}$ is provided. The value of the aerodynamic moment M_z is defined by $M_z=I_z\ddot{\alpha}$. In addition to measured in standard balance tests the complex of aerodynamic characteristics c_x (α), c_y (α), m_z (α), free oscillation technique allows to receive some non-stationary characteristics: static moment m_z^{α} and damping moment $m_z^{\omega_z}$.

Typical character of record of parameters at balance tests of free oscillating models of the reentry vehicle "Soyuz" in PGU-11 is presented in Fig. 5.

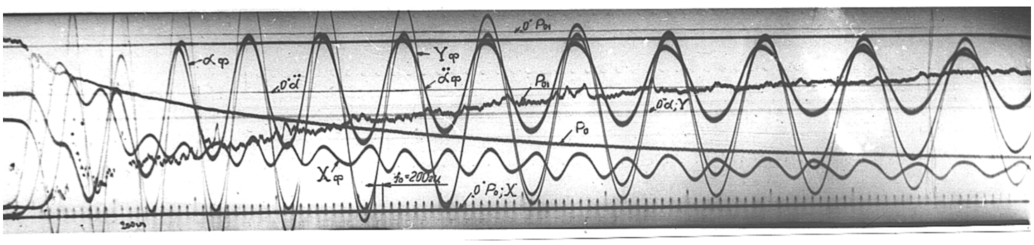

Fig. 5.

6. Conclusion

The test technique of measuring transient aerogasdynamic forces and moments realised in pulse (0.05-0.2 s) aerogasdynamic facilities of TSNIIMASH is based on recording during a test period 5-6 cycles of oscillation of springy measuring system “model-balance-support” or 5-6 cycles of model free oscillations. This provides aerodynamic characteristics with error less 5%. Each time relation of rigid, mass and inertia properties of the above system is chosen taking into consideration peculiarities of aerogasdynamic facility, modes and purposes of tests.

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